

CLAIMS

We Claim:

1. A method for processing a deformable element of a microstructure, comprising:  
deflecting the deformable element; and  
oxidizing the deformable element in an oxygen-containing gas other than air while the deformable element is in the deflected state.
2. The method of claim 1, wherein the deflected deformable element is a hinge of a micromirror device that further comprises a mirror plate attached to the hinge on a substrate of the micromirror device.
3. The method of claim 2, wherein the step of deflecting the deformable element further comprises: deflecting the deformable element to an ON state that corresponds to a state wherein the mirror plate is rotated to an ON state angle of from 10° to 18° degrees in a first rotation direction relative to the substrate.
4. The method of claim 2, wherein the step of deflecting the deformable element further comprising: deflecting the deformable element to an OFF state that corresponds to a state wherein the mirror plate is rotated to an OFF state angle of from -0.1° to -8° degrees relative to the substrate.
5. The method of claim 1, wherein the gas comprises more oxygen than is generally present in air.
6. The method of claim 1, wherein the oxygen-containing gas comprises ozone.
7. The method of claim 1, wherein the oxygen-containing gas comprises air mixed with H<sub>2</sub>O.
8. The method of claim 1, wherein the oxygen-containing gas comprises ozone mixed with H<sub>2</sub>O.

9. The method of claim 1, wherein the oxygen-containing gas comprises oxygen mixed with H<sub>2</sub>O.
10. The method of claim 1, wherein the oxygen-containing gas is oxygen plasma.
11. The method of claim 1, wherein the oxygen-containing gas comprises hydrogen peroxide.
12. The method of claim 1, wherein the oxygen-containing gas comprises acetic acid.
13. The method of claim 1, wherein the oxidization is performed at a temperature of from 100°C to 500°C degrees.
14. The method of claim 13, wherein the step of oxidizing further comprises: exposing the deformable element in the oxygen-containing gas for 1 minutes to 500 hours or more.
15. The method of claim 14, wherein the step of oxidizing further comprises: exposing the deformable element in the oxygen-containing gas for 50 hours or more.
16. The method of claim 14, wherein the step of oxidizing further comprises: exposing the deformable element in the oxygen-containing gas for 100 hours or more.
17. The method of claim 1, wherein the step of oxidizing further comprises: oxidizing an element of the microstructure, wherein the element comprises a material that is an elemental metal, metalloid or metallic compound.
18. The method of claim 1, wherein the step of oxidizing further comprises: oxidizing an element of the microstructure, wherein the element comprises a material that is a ceramic.
19. The method of claim 1, wherein the step of oxidizing further comprises: oxidizing an element of the microstructure, wherein the element comprises a material that is polycrystalline.

20. The method of claim 1, wherein the step of oxidizing further comprises: oxidizing an element of the microstructure, wherein the element comprises a material that is amorphous.
21. The method of claim 1, wherein the step of oxidizing further comprises: oxidizing an element of the microstructure, wherein the element comprises a material that is nanocrystalline.
22. The method of claim 1, wherein the step of oxidizing further comprises oxidizing an amount of the material equivalent to 20% or more of the volume of the deformable element.
23. The method of claim 1, wherein the step of oxidizing further comprises oxidizing an amount of the material equivalent to 50% or more of the volume of the deformable element.
24. The method of claim 1, wherein the step of oxidizing further comprises: oxidizing the element such that the electrical resistance of the element after oxidization is two times or more of the electrical resistance before oxidization.
25. The method of claim 1, wherein the step of oxidizing further comprises: oxidizing the element such that the electrical resistance of the element after oxidization is four times or more of the electrical resistance before oxidization.
26. The method of claim 1, wherein the mirror plate comprises:
  - a metallic reflective layer; and
  - a light transmissive protecting layer for protecting oxidization of the mirror plate during operation.
27. A method of processing a deflectable element of a microelectromechanical device, the method comprising:
  - oxidizing an amount of a material of the deflectable element equivalent to at least 20 percent of the volume of the deflectable element by exposing the deflectable element in an oxygen-containing gas other than air.

28. The method of claim 27, wherein the deformable element is a hinge of a micromirror device that further comprises a substrate and a mirror plate that is attached to the hinge such that the mirror plate is operable to rotate on the substrate, and wherein the oxidizing of the hinge reduces changes in a rest state of the mirror plate over time.
29. The method of claim 27, wherein the step of oxidizing further comprises:  
oxidizing the material of the deformable element at a temperature of from 100°C to 500°C.
30. The method of claim 29, wherein the step of oxidizing the material of the deformable element further comprises:  
oxidizing an amount of the material of the deformable element equivalent to at least 60 percent of the volume of the deformable element.
31. The method of claim 29, wherein the step of oxidizing the material of the deformable element further comprises:  
oxidizing the deformable element such that the plastic deformation of the is reduced by at least 20 percent after a time period of from 2 minutes to 10,000 hours.
32. The method of claim 27, further comprising:  
introducing the oxygen-containing gas to the deformable element through a micro-opening of an assembly in which the deformable element is encapsulated, wherein the micro-opening has a dimension around 10 micrometers or less.
33. The method of claim 27, wherein the step of introducing the oxygen-containing gas further comprises:
  - a) loading the assembly into a chamber;
  - b) introducing a first component of the oxygen-containing gas with a first pressure into the chamber; and
  - c) introducing a second component of the oxygen-containing gas with a second pressure higher than the first pressure into the chamber.

34. The method of claim 33, further comprising:
  - pumping out the chamber such that the pressure inside the chamber is lower than the first pressure; and
  - repeating the steps b) and c).
35. The method of claim 27, wherein the oxygen-containing gas comprises ozone.
36. The method of claim 27, wherein the oxygen-containing gas comprises air mixed with H<sub>2</sub>O.
37. The method of claim 27, wherein the oxygen-containing gas comprises ozone mixed with H<sub>2</sub>O.
38. The method of claim 27, wherein the oxygen-containing gas comprises oxygen mixed with H<sub>2</sub>O.
39. The method of claim 27, wherein the oxygen-containing gas is oxygen plasma.
40. The method of claim 27, wherein the oxygen-containing gas comprises hydrogen peroxide.
41. The method of claim 27, wherein the oxygen-containing gas comprises acetic acid.
42. The method of claim 27, wherein the step of oxidizing further comprises: oxidizing the deformable element that comprises a material that is an elemental metal, metalloid, ceramic or metallic compound.
43. The method of claim 27, wherein the step of oxidizing further comprises: oxidizing the deformable element comprising a material that is selected from a group comprising: polycrystalline, amorphous and nanocrystalline.

44. The method of claim 27, wherein the step of oxidizing further comprises: oxidizing the element such that the electrical resistance of the element after oxidization is two times or more of the electrical resistance before oxidization.

45. The method of claim 44, wherein the step of oxidizing further comprises: oxidizing the element such that the electrical resistance of the element after oxidization is four times or more of the electrical resistance before oxidization.

46. A method of making a micromirror device, comprising:  
providing a substrate;  
forming a mirror plate and hinge on a sacrificial material on the substrate such that the mirror plate is attached to the substrate via the hinge;  
removing the sacrificial material using a vapor phase etchant; and  
oxidizing the hinge in an oxygen-containing gas other than air.

47. The method of claim 46, wherein the vapor phase etchant comprises an interhalogen.

48. The method of claim 46, wherein the vapor phase etchant comprises a noble gas halide

49. The method of claim 48, wherein the noble gas halide is xenon difluoride.

50. The method of claim 46, wherein the step of forming the mirror plate and hinge further comprises:

depositing a first sacrificial layer on the substrate;  
forming a mirror plate on the first sacrificial layer;  
depositing a second sacrificial layer; and  
forming a hinge on the second sacrificial layer.

51. The method of claim 46, wherein the step of forming the mirror plate and hinge further comprises:

depositing a first sacrificial layer on the substrate;

- forming a hinge on the first sacrificial layer;
- depositing a second sacrificial layer; and
- forming a mirror plate on the second sacrificial layer.

52. The method of claim 46, wherein the gas comprises more oxygen than is generally presented in air

53. The method of claim 46, wherein the oxygen-containing gas comprises ozone.

54. The method of claim 46, wherein the oxygen-containing gas comprises air mixed with H<sub>2</sub>O.

55. The method of claim 46, wherein the oxygen-containing gas comprises ozone mixed with H<sub>2</sub>O.

56. The method of claim 46, wherein the oxygen-containing gas comprises oxygen mixed with H<sub>2</sub>O.

57. The method of claim 46, wherein the oxygen-containing gas is oxygen plasma.

58. The method of claim 46, wherein the oxygen-containing gas comprises hydrogen peroxide.

59. The method of claim 46, wherein the oxygen-containing gas comprises acetic acid.

60. The method of claim 46, wherein the oxidization is performed at a temperature of from 300°C to 500°C degrees.

61. The method of claim 46, wherein the hinge comprises a material that is an elemental metal, metalloid or metallic compound.

62. The method of claim 46, wherein the hinge comprises a material that is ceramic.

63. The method of claim 46, wherein the hinge comprises a material that is polycrystalline.
64. The method of claim 46, wherein the hinge comprises a material that is amorphous.
65. The method of claim 46, wherein the step of oxidizing further comprises: oxidizing an amount of a material of the hinge equivalent to 20% or more in volume of the hinge.
66. The method of claim 46, wherein the step of oxidizing further comprises oxidizing an amount of a material of the hinge equivalent to 50% or more in volume of the hinge.
67. The method of claim 46, wherein the step of oxidizing further comprises: oxidizing the element such that the electrical resistance of hinge after oxidization is two times or more of the electrical resistance before oxidization.
68. The method of claim 46, wherein the step of oxidizing further comprises: oxidizing the hinge such that the electrical resistance of the element after oxidization is four times or more of the electrical resistance before oxidization.
69. A method of making a micromirror device, comprising:
  - providing a substrate;
  - forming a mirror plate and hinge on a sacrificial material on the substrate such that the mirror plate is attached to the substrate via hinge;
  - removing a portion of the sacrificial material using a vapor phase etchant such that at least a portion of the hinge is exposed;
  - oxidizing the exposed hinge in an oxygen-containing gas other than air; and
  - removing the remaining sacrificial material.
70. The method of claim 69, wherein the step of forming the mirror plate and hinge further comprises:
  - depositing a first sacrificial layer on the substrate;

forming a mirror plate on the first sacrificial layer;  
depositing a second sacrificial layer; and  
forming a hinge on the second sacrificial layer.

71. The method of claim 69, wherein the step of forming the mirror plate and hinge further comprises:

depositing a first sacrificial layer on the substrate;  
forming a hinge on the first sacrificial layer;  
depositing a second sacrificial layer; and  
forming a mirror plate on the second sacrificial layer.

72. The method of claim 69, wherein the gas comprises more oxygen than is generally presented in air.

73. The method of claim 69, wherein the oxygen-containing gas comprises ozone.

74. The method of claim 69, wherein the oxygen-containing gas comprises air mixed with H<sub>2</sub>O.

75. The method of claim 69, wherein the oxygen-containing gas comprises ozone mixed with H<sub>2</sub>O.

76. The method of claim 69, wherein the oxygen-containing gas comprises oxygen mixed with H<sub>2</sub>O.

77. The method of claim 69, wherein the oxygen-containing gas is oxygen plasma.

78. The method of claim 69, wherein the oxygen-containing gas comprises hydrogen peroxide.

79. The method of claim 69, wherein the oxygen-containing gas comprises acetic acid.

80. The method of claim 69, wherein the oxidization is performed at a temperature of from 300°C or more.
81. The method of claim 69, wherein the hinge comprises a material that is an elemental metal, metalloid or metallic compound.
82. The method of claim 69, wherein the hinge comprises a material of SiN<sub>x</sub>, TiN<sub>x</sub> or TiSi<sub>x</sub>Ny.
83. The method of claim 69, wherein the hinge comprises a material that is polycrystalline.
84. The method of claim 69, wherein the hinge comprises a material that is amorphous.
85. The method of claim 69, wherein the step of oxidizing further comprises oxidizing an amount of a material of the hinge equivalent to 70% or more in volume of the hinge.
86. The method of claim 69, wherein the step of oxidizing further comprises: oxidizing the element such that the electrical resistance of hinge after oxidization is six times or more of the electrical resistance before oxidization.
87. The method of claim 69, wherein the step of oxidizing further comprises: oxidizing the hinge such that the electrical resistance of the element after oxidization is eight times or more of the electrical resistance before oxidization.
88. The method of claim 69, wherein the gas etchant comprises XeF<sub>2</sub>.
89. A method of making a micromirror device, comprising:
  - providing a substrate;
  - depositing a hinge layer and a mirror plate layer on a sacrificial material on the substrate;
  - oxidizing and patterning the hinge layer to form an oxidized hinge; and

removing the sacrificial layer.

90. The method of claim 89, wherein the step of patterning is performed before oxidizing the hinge layer.

91. The method of claim 89, wherein the step of patterning is performed after oxidizing the hinge layer.

92. The method of claim 89, wherein the step of oxidizing the hinge further comprises: oxidizing the hinge in an oxygen-containing gas.

93. The method of claim 90, wherein the gas comprises more oxygen than is generally presented in air

94. The method of claim 90, wherein the oxygen-containing gas comprises ozone.

95. The method of claim 90, wherein the oxygen-containing gas comprises air mixed with H<sub>2</sub>O.

96. The method of claim 90, wherein the oxygen-containing gas comprises ozone mixed with H<sub>2</sub>O.

97. The method of claim 90, wherein the oxygen-containing gas comprises oxygen mixed with H<sub>2</sub>O.

98. The method of claim 90, wherein the oxygen-containing gas is a downstream oxygen plasma.

99. The method of claim 90, wherein the oxygen-containing gas comprises hydrogen peroxide.

100. The method of claim 90, wherein the oxygen-containing gas comprises acetic acid.

101. The method of claim 90, wherein the hinge comprises a material that is an elemental metal, metalloid or metallic compound.
102. The method of claim 90, wherein the hinge comprises a material that is ceramic.
103. The method of claim 90, wherein the hinge comprises a material that is polycrystalline.
104. The method of claim 103, wherein the hinge comprises a material that is amorphous.
105. The method of claim 90, wherein the step of oxidizing further comprises oxidizing 20% or more in thickness of the hinge.
106. A method of making a micromirror device, comprising:  
    providing a substrate;  
    forming a mirror plate and hinge on a sacrificial layer on the substrate such that the mirror plate is attached to the substrate via the hinge;  
    removing the sacrificial layer; and  
    cleaning and oxidizing the micromirror device, further comprising:  
        providing a gas that is an oxygen-containing gas other than air, the oxygen-containing gas cleaning the micromirror and oxidizing an amount of the material of the hinge equivalent to at least 25% in volume of the hinge.
107. The method of claim 106, wherein the oxygen-containing gas comprises ozone.
108. The method of claim 106, wherein the oxygen-containing gas comprises air mixed with H<sub>2</sub>O.
109. The method of claim 106, wherein the oxygen-containing gas comprises ozone mixed with H<sub>2</sub>O.

110. The method of claim 106, wherein the oxygen-containing gas comprises oxygen mixed with H<sub>2</sub>O.

111. The method of claim 106, wherein the oxygen-containing gas is oxygen plasma.

112. The method of claim 106, wherein the oxygen-containing gas comprises hydrogen peroxide.

113. The method of claim 106, wherein the oxygen-containing gas comprises acetic acid.

114. The method of claim 106, wherein the hinge comprises a material that is an elemental metal, metalloid or metallic compound.

115. The method of claim 106, wherein the hinge comprises a material that comprises titanium and aluminum.

116. The method of claim 106, wherein the hinge comprises a material that is polycrystalline.